

**CALIFORNIA DEPARTMENT OF CONSERVATION
DIVISION OF MINES AND GEOLOGY**

**FAULT EVALUATION REPORT FER-218
LIKELY FAULT ZONE,
LASSEN AND MODOC COUNTIES, CALIFORNIA**

by
William A. Bryant
Associate Geologist
August 13, 1990
(Revised March 20, 1991)

California Department of Conservation
Division of Mines and Geology
630 Bercut Drive
Sacramento, CA 95814

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INTRODUCTION

Potentially active faults in the Canby-Madeline Plains study area of southern Modoc County and northern Lassen County that are evaluated in this Fault Evaluation Report (FER) include faults that comprise the Likely fault zone (Figure 1). The Canby - Madeline Plains study area is located in parts of the Alturas, Canby, Likely, Madeline, Observation Peak, and Ravendale 15-minute quadrangles (Figure 1).

Faults in the Canby-Madeline Plains study area are evaluated as part of a statewide effort to evaluate faults for recency of activity. Those faults determined to be sufficiently active (Holocene) and well-defined are zoned by the State Geologist as directed by the Alquist-Priolo Special Studies Zones Act of 1972 (Hart, 1988).

SUMMARY OF AVAILABLE DATA

The Canby-Madeline Plains study area is located in the Modoc Plateau geomorphic province. The Modoc Plateau is characterized by extensive volcanic rocks of late Tertiary and Quaternary age displaced by many north to northwest-trending normal faults. The Likely fault zone, a northwest-trending feature, generally forms the boundary between northwest-trending faults to the south and more northerly trending faults to the north (Figure 1). East-west directed extension characterizes the most recent stress regime in the Canby-Madeline Plains study area, which has resulted in north-trending normal faults.

Topography in the study area ranges from the flat surfaces of the Madeline Plains in the southern part of the study area and the Devils Garden Basalt in the northern part of the study area to hills of moderate relief between Canby and the Madeline Plains (Figure 1). Elevations in the study area range from 1300 meters along the Pit River drainage to the summit of Observation Peak at 2427 meters. Development in the study area is relatively low. The town of Alturas is the largest settlement within 22 km of the Likely fault zone, with the settlement of Madeline lying closest to the mapped trace of the fault. Agriculture (farming and cattle grazing) is the principal activity in the study area.

Rocks in the study area are predominately volcanic flow and pyroclastic rocks of late Tertiary to Pleistocene age (Gay and Aune, 1958; Lydon and others, 1960; CDWR, 1963; Potter, 1988; Weick, 1990). Quaternary deposits include Pleistocene and Holocene fluvial deposits in the Pit River drainage,

Pleistocene and Holocene (?) alluvium in several small basins along the Likely fault, and Pleistocene and Holocene lacustrine and alluvial deposits in the Madeline Plains area.

Mapping by Gay and Aune (1958; unpublished field maps), CDWR (1963), Gay (unpublished field map), Burnett (unpublished aerial photographic interpretation), and Weick (1990) will be evaluated in this FER. The majority of mapping along the Likely fault zone has been reconnaissance in nature and is reflected by small-scale mapping such as Gay and Aune (1958), Lydon and others (1960), and Burnett. The only detailed studies of the Likely fault zone were by Potter (1988) near the northern end of the fault zone in the Canby-Pit River area and by Weick (1990) at the southern end of the fault in the Madeline Plains.

Aerial photographic interpretation by this writer of faults in the Canby-Madeline Plains study area was accomplished using aerial photographs from the U.S. Department of Agriculture (BUW, 1955) and the U.S. Bureau of Land Management (CA02, 1978). In addition, small scale U.S. Geological Survey photos (VVHU, 1953) were used to provide a more regional perspective in the southern part of the study area. The main emphasis of this FER is to photo-check previously mapped traces of the Likely fault zone rather than complete an independent photo interpretation. Selected fault traces mapped by this writer were mapped where geomorphic features were well-defined or where faults mapped by others seemed to be mislocated due to the small scale of the original mapping.

Four and one-half days were spent in the field in early July 1990. Selected geomorphic features were field checked and subtle features not observable on the aerial photographs were mapped. Results of aerial photographic interpretation and field observations by this writer are summarized on Figures 2a - 2f.

LIKELY FAULT ZONE

BACKGROUND

The Likely fault zone has been described as an 85 to 95 km long, northwest-trending fault in the southern Modoc Plateau. It was reported that the Likely fault is characterized by geomorphic features indicative of recent, significant right-lateral strike-slip displacement, such as "sag ponds and offset drainage lines" (CDM, 1959; Macdonald, 1966). Various workers through the years have considered the Likely fault to be at least potentially active (i.e. Quaternary active), while others have concluded that the fault has probably been active in Holocene time (e.g. Woodward-Clyde Consultants, 1978; Slemmons, 1979; LaForge and Hawkins, 1986; Weick, 1990). LaForge and Hawkins (1986) reported that the Likely fault displaces Holocene alluvial and lacustrine deposits, based on mapping by Gay and Aune (1958). LaForge and Hawkins further stated that the fault is delineated by geomorphic features indicative of strike-slip displacement, such as "offset drainages, sag ponds, linear troughs, and shutter ridges". However, no map of the Likely fault zone was provided by LaForge and Hawkins.

The amount of cumulative displacement along the Likely fault is not known. LaForge and Hawkins reported that the amount of Quaternary displacement could be on the order of hundreds of meters. This amount was based on Macdonald (1966), although a check of this reference indicates that Macdonald did not report the amount of displacement for the Likely fault. Weick (1990) stated that from 1.5 to 2 km of right-lateral displacement was indicated by Gay and Aune (1958) and Lydon and others (1960). It is not clear what this amount is based on, because Gay and Aune (1958), CDM (1959), and Lydon and others (1960) never reported the amount of displacement for the Likely fault. Weick does indicate that

the 2 km figure is based on "stream offsets" and refers to Gay and Aune (1958) and Lydon and others (1960).

The Likely fault is characterized by well-defined aeromagnetic anomalies along its trace southeast of Ballard Reservoir (Chase and Mattison, 1989) (Figures 1, 2a). These anomalies suggest a juxtaposition of rock units with different magnetic properties by faulting, but do not indicate recency of faulting. There is no evidence of significant changes across the trace of the Likely fault, based on gravity surveys (Chapman and others, 1968).

Potter (1988) mapped an area in the Canby quadrangle that extended 15 km northwest and 9 km southeast of the Pit River (Potter not plotted on Figure 2a). Potter concluded that there is no evidence for a major strike-slip fault along the trend of the Likely fault and that no obvious fault zone exists in her study area. Significantly, the Pliocene Devils Garden Basalt is not offset along the mapped trace of the fault and tilting and faulting are limited to geologic units older than the Devils Garden Basalt.

Howard (1988) evaluated traces of the Likely fault zone, based on aerial photographic interpretation and field inspection. Howard concluded that the Likely fault is "...a series of discontinuous photolineaments, some of which are inactive normal faults, but others merely are bedding contacts or other on-strike geomorphic features produced by differential erosion". Howard found no systematic deflection of drainages to support recent right-lateral displacement. He concluded that, where stream deflections occur, they could be explained by differential erosion. Basin deposits of late Pleistocene to Holocene age are not disturbed along the trace of the Likely fault. Howard also reported that at several locations along the fault continuous, unfaulted bedrock outcrops were observed.

Howard reported that no offset of latest Pleistocene high-stand shorelines (probably 13-15 ka) in either a right-lateral or vertical sense were observed in the Madeline Plains area. He observed that the shoreline features had a distinctly fresher appearance than scarps observed along strands of the Likely fault.

Traces of the Likely fault zone mapped by Gay and Aune (1958), CDWR (1960), Burnett (unpublished), Gay (unpublished), and Weick (1990) will be discussed by quadrangle from north to south.

CANBY QUADRANGLE

Literature Review

The original field maps of Gay and Aune (1958) showed the Likely fault as a single trace in the Canby quadrangle. These field maps did not show the Likely fault to extend northwest beyond the Pit River near Canby (Figure 2a). However, the 1:250,000 Alturas Sheet depicts the fault as continuing to the northwest across the Pit River through Howard Gulch (Figure 1). The fault is mapped as concealed by Holocene alluvium in the Pit River floodplain and also concealed by the Pliocene Alturas Formation for about 3 km north of the Pit River. It should be pointed out that faults shown on the Alturas Sheet with dashed lines, normally symbolizing an approximately located fault, were intended to be shown as concealed (C. Jennings, p.c., April 1990). Farther northwest the fault is mapped as offsetting the Alturas Formation and extending into and offsetting the Pliocene Devils Garden Basalt. The Devils Garden Basalt was thought to be Pleistocene by Gay and Aune (1958). However, several K-Ar ages for this unit indicate a late Miocene to Pliocene age (McKee and others, 1983). Gay and Aune depicted the fault as

concealed by late Pleistocene to Holocene alluvium (age of unit not known) in the Ballard Reservoir - White Reservoir area (Figure 2a).

CDWR (1963) mapped the Likely fault as having two traces south of the Pit River. The faults border the ridge-top basins of Ballard and White Reservoirs, but do not offset latest Pleistocene to Holocene alluvium (Figure 2a). The Likely fault does not offset alluvial deposits of the Pit River, except for a possible terrace near the airstrip on the south side of the Pit River (locality 1, Figure 2a). North of the Pit River the Likely fault mapped by CDWR is inferred to offset the Pliocene Alturas Formation, but alluvial deposits just south of Howard Gulch are not offset. CDWR extended the fault through Howard Gulch and depicted the Devils Garden Basalt as offset by the fault (Figure 2a).

Aerial Photographic Interpretation and Field Observations

The Likely fault in the Canby quadrangle is poorly defined and lacks geomorphic evidence of latest Pleistocene to Holocene right-lateral strike-slip or vertical displacement (Figure 2a). The plateau underlain by Pliocene Devils Garden Basalt at the northern end of Howard Gulch is a key geomorphic surface in which to test the presence of an active fault (locality 2, Figure 2a). This surface lacks geomorphic evidence of a major right-lateral strike-slip or vertical fault. Unfaulted basalt flows could be followed across the mapped trace of the Likely fault (Figure 2a). In addition, near-horizontal beds of early Pliocene Alturas Formation were unfaulted across the mapped trace of the Likely fault at locality 3 (Figure 2a). It was not possible to observe the entire railroad cut, but the relatively undisturbed beds of the Alturas Formation indicate a lack of significant strike-slip faulting in this area.

The mapped trace of the Likely fault was not verified in Pliocene Alturas Formation just south of Howard Gulch (locality 4, Figure 2a). No evidence of recent faulting was observed in the Pit River drainage, although terraces are not well-developed along the Pit River floodplain. Significantly, the Pit River is not offset or deflected in a right-lateral sense where crossed by the Likely fault, nor does the gradient increase due to vertical displacement.

South of the Pit River, northeast-dipping beds of the Miocene Cooley Gulch Formation (Potter, 1988) form prominent strike ridges. Traces of the Likely fault were mapped parallel to the strike of these pyroclastic and lava flow units. There is no systematic deflection of drainages, ridges that cross the trend of the fault are not offset, and bedding/flow structures where exposed are continuous across the fault (localities 1, 5-6, Figure 2a). A north-trending fault mapped by Potter (1988) was verified as crossing the trend of the Likely fault with no evidence of offset (locality 7, Figure 2a). There is no geomorphic evidence of recent faulting along this north-trending fault.

Closed basins along ridgetops between Canby and Ballard Reservoir are not associated with other geomorphic evidence of recent strike-slip or normal faulting (Figure 2a). It is possible that these closed basins were formed by ridgetop spreading and/or local landsliding. The valley and ponded alluvium in the vicinity of Ballard Reservoir are probably due to differential erosion along tilted strata.

ALTURAS QUADRANGLE

Literature Review

The Likely fault splays into two traces in the Canyon Creek area as mapped by Gay and Aune (Figure 2b). The southern trace is mapped as offsetting alluvial deposits in the vicinity of Bayley

Reservoir. In contrast to Gay and Aune, CDWR (1963) mapped the southern trace of the Likely fault as concealed by late Pleistocene to Holocene alluvium (Figure 2b).

Both Gay and Aune and CDWR mapped the northern trace of the Likely fault along the southwest-facing escarpment of Graven Ridge (a bedrock escarpment consisting of probable Miocene basalt to basaltic andesite) (Figure 2b). Both Delta Lake and Alkali Lake in the southern part of the map are closed depressions that were assumed to have formed by recent displacement along the Likely fault.

Aerial Photographic Interpretation and Field Observations

The Likely fault is delineated by a southwest-facing scarp in bedrock (Graven Ridge) through most of the Alturas quadrangle (Figure 2b). A broad, generally linear trough west of Graven Ridge ponded alluvium and is indicative of late Quaternary strike-slip faulting. However, geomorphic evidence of Holocene right-lateral strike-slip displacement is lacking. Specifically, there is no systematic deflection of drainages and several drainages developed in bedrock are not offset across the fault (e.g. localities 8-11, Figure 2b). The large-scale right-lateral deflection of Hilton Creek suggests right-lateral offset but may be due to differential erosion around Graven Ridge. Hilton Creek is not offset at the point where it crosses the Likely fault (locality 11, Figure 2b). Canyon Creek to the northwest is deflected in a left-lateral sense around Graven Ridge.

The Canyon Creek drainage provides a nearly continuous exposure of flow surfaces. Unfaulted basalt flows were observed in a tributary to Canyon Creek by this writer where crossed by the southern trace of the Likely fault mapped by Gay and Aune (1958) and CDWR (1960) (locality 12, Figure 2b). The prominent tonal lineament delineating the southern trace of Burnett (unpublished) is actually a resistant basalt unit exposed along the strike ridge (locality 13, Figure 2b).

Eastern traces of the Likely fault mapped by Burnett, CDWR, and Gay and Aune cross apparently continuous, unfaulted basalt flow surfaces at locality 14 (Figure 2b). This indicates a lack of significant lateral or vertical displacement. The closed basins of Delta Lake and Alkali Lake lack associated geomorphic evidence of recent strike-slip or vertical displacement. These closed basins may be more closely related to volcanic rather than tectonic processes.

LIKELY QUADRANGLE

Literature Review

The Likely fault zone mapped by Gay and Aune, CDWR, and Burnett (unpublished) splays into a zone of northwest-trending faults about 4 km wide in the Likely quadrangle (Figure 2c). The fault zone is located entirely within Mio-Pliocene volcanic rocks in this area. The principal trace of the Likely fault, located along the southwest side of Delta Lake, extends southeast and deflects Stones Canyon in a right-lateral sense and continues along the base of a broad linear trough in bedrock and a northeast facing bedrock escarpment (Figure 2c).

Faults mapped by Gay and Aune, CDWR, and Burnett east of the principal trace of the Likely fault are characterized by relatively short, sub-parallel northwest-trending faults in bedrock (Figure 2c). These sub-parallel faults extend for about 5 km southeast of Delta Lake.

Aerial Photographic Interpretation and Field Observations

Traces of the Likely fault in the Likely quadrangle mapped by Gay and Aune, CDWR, and Burnett were not verified as recently active by this writer, based on air photo interpretation (Figure 2c). There is no evidence of systematic right-lateral deflection or vertical offset of drainages and individual traces lack the detailed geomorphic evidence associated with Holocene right-lateral or vertical displacement (Figure 2c). However, late Quaternary strike-slip displacement is indicated by the broad linear trough and northeast-facing scarp in bedrock (Figure 2c). Springs and closed depressions along the mapped traces of the Likely fault zone in this area are clearly related to active landsliding. The broad zone of sub-parallel faults southeast of Delta Lake are generally related to large-scale gravity failures into the South Fork Pit River drainage (Figure 2c).

MADELINE QUADRANGLE

Literature Review

The Likely fault zone mapped by both Gay and Aune and CDWR is delineated by two traces that form a zone up to 3.3 km wide (Figure 2d). The eastern trace mapped by Gay and Aune juxtaposes bedrock against alluvium on the east side of Mitchell Field (locality 15, Figure 2d). The eastern trace shown on Gay and Aune's field map differs somewhat from that shown on the 1:250,000 Alturas Sheet in the Sage Hen Flat area (locality 16, Figure 2d). Specifically, the trace depicted on the field map trends through the middle of Sage Hen Flat, but is not shown to offset ponded alluvium. The trace shown on the Alturas Sheet (not plotted on Figure 2d) is located west of Sage Hen Flat, similar to the trace mapped by CDWR (1963).

The western trace mapped by Gay and Aune trends more north-south and is delineated by discontinuous strands that terminate just south of the western flank of Mitchell Hill (locality 15, Figure 2d). The fault does not offset alluvium north of Madeline (locality 17, Figure 2d). The western trace mapped by CDWR extends farther southeast than the trace mapped by Gay and Aune. The fault is concealed by latest Pleistocene to Holocene alluvium in the northern part of the Madeline Plains east of Madeline (Figure 2d).

There are north and northwest-trending faults mapped by CDWR and Gay and Aune located both east and west of the Likely fault. Only those faults closest to the Likely fault zone were plotted on Figure 2d. None of these branch faults were mapped as offsetting late Pleistocene to Holocene alluvium.

Aerial Photographic Interpretation and Field Observations

Strands of the Likely fault in the Madeline quadrangle generally are poorly defined and lack geomorphic evidence of latest Pleistocene to Holocene faulting (Figure 2d). The western branch of the Likely fault mapped by Gay and Aune and CDWR, delineated by a linear drainage and an eroded backfacing scarp, is poorly defined and lacks geomorphic evidence of recent faulting. A near-horizontal basalt flow located across the trace of this fault is clearly unfaulted (locality 18, Figure 2d).

The principal (northeastern) trace of the Likely fault zone in the Madeline quadrangle is moderately defined and is marked by two large closed basins (Sage Hen Flat and Mitchell Field) and both northeast and southwest-facing bedrock escarpments (Figure 2d). Both Sage Hen Flat and Mitchell Field, thought

to be formed by recent movement along the Likely fault, are not associated with well-defined, right-stepping segments of the Likely fault. Mitchell Field is clearly related to the formation of Mitchell Hill, a volcanic cone of probable Pliocene age (Figure 2d). Similarly, Sage Hen Flat is probably related to the emplacement of Tule Mountain (Figure 2d).

Geomorphic evidence suggestive of late Quaternary right-lateral displacement locally is present along the northeastern trace of the Likely fault zone at localities 19 and 20 (Figure 2d). A linear ridge in bedrock and a possible right-laterally deflected drainage at locality 19 are associated with a slightly sinuous bedrock escarpment (Figure 2d). South of Clark Valley Road the Likely fault is delineated by a moderately well-defined southwest-facing bedrock escarpment, sidehill trough, oversteepened talus slope, and linear trough (locality 20, Figure 2d). The fault trace south of field locality B is much less well defined. Coincidentally, a resistant volcanic unit in which the moderately well-defined scarp is located ends. This suggests that the geomorphic features indicating recent faulting to the northwest may in fact be due to differential erosion rather than recent faulting.

RAVENDALE and OBSERVATION PEAK QUADRANGLES

Literature Review

The Likely fault zone splays into several northwest-trending branches forming a zone up to 10 km wide in the Ravendale and Observation Peak quadrangles (Figures 2e and 2f). There is reasonably good agreement with respect to location between the mapping of Gay (unpublished), CDWR (1963), and Weick (1990), although differences exist (Figures 2e and 2f). The principal difference is the mapping of Weick, who reported that branches of the Likely fault offset Holocene alluvium (Weick's faults B, C, D, and E; Figures 2e and 2f). In contrast, none of the faults mapped by Gay and CDWR are interpreted as offsetting lacustrine or alluvial deposits.

Weick considered that his faults D and E have evidence of Holocene activity and that they represent the southernmost extent of the Likely fault. Specifically, Weick stated that there is a subtle "sag depression" in post-5 ka alluvium between faults D and E and that there are distinct tonal lineaments that delineate these faults. Weick mapped Fault D to the southeast across Madeline Plains and along the eastern flank of Observation Peak (Figure 2f). To the north of Madeline Plains Weick stated that faults D and E merge and are delineated by a linear drainage in bedrock. Weick also stated that these faults cut shorelines in Madeline Plains.

A group of more northerly trending bedrock faults mapped by both CDWR and Weick are located north of the Likely fault in the Observation Peak qd. (Figure 2f). Fault zones F and G offset latest Pleistocene to Holocene lacustrine deposits as mapped by Weick (Figure 2f). Faults mapped by CDWR do not offset latest Pleistocene and Holocene lacustrine deposits (Figure 2f).

Aerial Photographic Interpretation and Field Observations

Mapping by Weick (1990) is the most current and detailed to date for the Likely fault zone. As such, Weick's mapping will be given careful evaluation on a trace by trace basis in this FER.

Fault A

Weick's Fault A lacks geomorphic evidence of recent right-lateral or normal faulting. There are a number of ridges and drainages developed in resistant bedrock that are crossed by Fault A and lack evidence of late Quaternary right-lateral deflection or vertical offset (Figure 2e). The closed depression Weick reported on Juniper Ridge was not verified by this writer.

Fault A mapped by CDWR (1963) and Gay did not extend south to the Juniper Ridge area. I see no compelling geomorphic evidence to extend the fault as far south as does Weick.

Skeleton Flat is an area of ponded alluvium and was once a closed depression that now drains to the north (locality 21, Figure 2e). Weick postulated that Skeleton Flat is a rhombochasmic basin formed by en echelon strands of Fault A. I did not verify the existence of a right or left-stepping pattern for Fault A. It seems more plausible that Skeleton Flat was formed by the disruption of established drainage patterns when MacDonald Peak (a Pliocene volcanic cone) was emplaced.

Fault B

Weick's Fault B is generally moderately to poorly defined in bedrock and is delineated by geomorphic features, such as linear drainages, that are characteristic of erosion along a bedrock fault. Weick mapped the fault southeast into the Madeline Plains, based on a tonal lineament in alluvium (locality 22, Figure 2e). A sharp tonal lineament was observed by this writer based on air photo interpretation, but this feature may be artificial because it seems to connect a windmill to the northwest with an irrigated field to the southeast. This tonal was not visible during the field inspection by this writer (and Weick indicated that he was unable to verify the feature in his field mapping).

Weick mapped several branch faults northwest of Madeline Plains that splay to the west of Fault B (Figure 2e). These are moderately defined, short, normal faults delineated by north-facing scarps in bedrock. These faults are confined to the young (~4 ma) volcanic cone and may be related to the emplacement of this feature. I did not verify the continuation of these faults east to Fault B.

Fault C

Weick's Fault C is delineated by an eroded west-facing scarp in bedrock and a linear drainage, neither of which are indicative of recent faulting (Figure 2e). Two drainages are deflected right-laterally near the fault, but the deflections in bedrock are not sharp, are not associated with additional geomorphic features indicative of recent faulting, and can be explained by erosion. The fault was mapped in the northern Madeline Plains by Weick, based on a tonal lineament in alluvium, aligned springs, well-defined linear drainage and apparent offset drainage. The tonal lineament was verified by this writer, based on air photo interpretation, but there is no evidence of a tonal, vegetation contrast, or scarp in the field (Figure 2e). Late Pleistocene high stand shorelines do not appear to be offset by Fault C, although the shorelines are locally obscured or concealed by slope debris (Figure 2e).

Fault D

North of the Madeline Plains, Weick's Fault D is poorly defined in bedrock and is delineated by a crudely linear drainage and linear tonal contrasts in bedrock (Figure 2e). This fault lacks geomorphic

evidence of recent faulting (such as sidehill benches, scarps, offset or deflected drainages). Fault D in bedrock just north of the road in section 14, T35N, R15E (Figure 2f) is delineated by a diffuse tonal lineament, but the fault lacks geomorphic evidence of recent faulting, such as a trough, or scarp. An east-facing bedrock escarpment is located about 50 meters east of Fault D, but this scarp is probably erosional. Also, if the scarp had been formed by recent strike-slip faulting, the sense of offset of the ridge would be more consistent with left-lateral offset.

The tonal lineament in Madeline Plains that delineates Fault D was partly verified by this writer south of the road in section 14 (Figure 2f). The tonal lineament observed in the field is a somewhat diffuse vegetation contrast - geomorphic evidence of recent faulting was not observed. The tonal lineament is in places fairly sharp, but my mapping differs somewhat from that of Weick (Figure 2f). The "sag depression" noted by Weick between faults D and E is best described as a very broad, poorly defined trough that may not be related to tectonic processes (Figure 2f). The trough does not seem to be closed to the southeast and may be fluvial.

There are at least two hypothesis for the existence of the tonal lineament that delineates Fault D. One is the theory of Weick, that the lineament indicates recent faulting. However, this theory is not consistent with the geomorphic expression of the fault in resistant bedrock to the northwest, which indicates that the fault is not active. An alternate hypothesis is that the tonal lineament delineating Fault D in the northern Madeline Plains reflects the presence of an old, inactive fault in bedrock that lies just below the surface in this area. The tonal lineament is probably not related to recent surface fault rupture.

Fault D was not verified by this writer southeast of section 23, T35N, R15E (Figure 2f). The trace mapped by Weick along the northeastern flank of Observation Peak has no geomorphic expression (such as scarps, deflected drainages, deflected ridges) and prominent shoreline features are not offset where crossed by the mapped trace (locality 23, Figure 2f). There is a minor fault in bedrock near the trace mapped by Weick, but this fault also does not offset shoreline features and lacks geomorphic features indicative of recent faulting (Figure 2f).

Fault E

Fault E mapped by Weick is a tonal lineament in Weick's postulated "Fallon Formation" (a presumed 5 ka deposit; see discussion of Weick's Quaternary stratigraphy). Fault E was not verified by this writer except for poorly defined, discontinuous tonals in alluvium as indicated on Figure 2f.

SELECTED NORTH-TRENDING FAULTS NEAR LIKELY FAULT ZONE

Several north-trending faults near the Likely fault zone were mapped by CDWR (1963) and Burnett (unpublished) in the Likely quadrangle and by CDWR (1963) and Weick (1990) (his faults F and G) in the Ravendale and Observation Peak quadrangles (Figures 2c, 2e, and 2f).

LIKELY QUADRANGLE

Literature Review

Burnett mapped a northwest-trending fault that extends into the northwest corner of the Madeline Plains (Figure 2c). This fault, which will be referred to in this FER as the Nelson Corral fault, is shown

to offset latest Pleistocene to Holocene lacustrine deposits. Although Burnett did not map this unit northwest into bedrock north of the Madeline Plains, the fault projects into a bedrock fault mapped by Gay and Aune (1958) and CDWR (1963) (Figure 2c). This fault in bedrock is characterized by a more northerly trend and a prominent east-facing bedrock escarpment. This fault may connect with the Likely fault zone in the vicinity of South Fork Mountain.

Aerial Photographic Interpretation and Field Observations

Nelson Corral Fault

The Nelson Corral fault mapped by Burnett (unpublished) is delineated by vague, discontinuous tonal lineaments in alluvium and lacustrine deposits of the Madeline Plains (Figure 2c). These lineaments are not associated with geomorphic evidence of recent faulting, such as scarps or troughs, based on field inspection by this writer. These lineaments align with a bedrock fault to the north mapped by CDWR. Late Pleistocene shorelines are not well-defined where crossed by the bedrock fault, so it is unclear whether or not the bedrock fault offsets the high-stand shoreline.

The Nelson Corral fault changes to a more northerly trend north of the Madeline Plains. The fault is delineated by a crude linear drainage and a moderately defined east-facing scarp that is as high as 97 meters (Figure 2c). The bedrock scarp is generally not sharp and lacks geomorphic evidence of latest Pleistocene to Holocene displacement, although minor late Quaternary displacement is possible. The freshest geomorphic features were observed at the northern end of this escarpment just south of South Fork Mountain (Figure 2c). A moderately well-defined graben probably formed in response to ridgetop spreading, indicated by the probable association with a landslide scarp to the east. The ridgetop and large-scale landslide features near South Fork Mountain may be caused by intense shaking of a nearby earthquake, possibly on the Likely or Nelson Corral fault in late Quaternary time.

Traces 1 and 2

Two additional tonal lineaments (referred to as Traces 1 and 2) were observed southwest of the Nelson Corral fault by this writer, based on air photo interpretation (Figure 2c). These lineaments are sub-parallel to Burnett's Nelson Corral fault. Traces 1 and 2 are delineated by vague to locally well-defined tonal lineaments in alluvial and lacustrine deposits (Figure 2c). Trace 1 is in part better defined than the Nelson Corral fault in the Madeline Plains (Figure 2c). However, the southern part of this feature passes diagonally through the middle of a plowed field and may be artificial. There are several short tonal lineaments in sec 25, T37N, R12E that are probably beach ridges or sand dunes. It is significant that well-defined late Pleistocene high stand shorelines are not offset along the northern projections of Traces 1 and 2 (Figure 2c).

RAVENDALE AND OBSERVATION PEAK QUADRANGLES

Fault F

Fault F is a zone of north to northwest-trending normal faults with down to the west vertical displacement in bedrock mapped by Weick (1990) (Figure 2f). The southern end of Fault F extends into latest Pleistocene to Holocene lacustrine deposits at the southern end of Cold Spring Valley. Weick

reported that these features consisted of "low-height normal-slip scarps and vegetational lineaments that extend about 1.2 km into Madeline Plains". Weick was unable to field check these features because they were under water during his field investigation.

The principal trace of Fault F is delineated by a well-defined west-facing scarp in bedrock. The fault appears to be delineated by tonal lineaments in alluvium and a scarp in an alluvial fan at its southern end, based on air photo interpretation by this writer (locality 24, Figure 2f). The scarp in the alluvial fan was clearly formed by shoreline processes, based on field checking by this author. The "low-height normal-slip scarps" reported by Weick were not verified by this writer, based on field observations (field locality F, Figure 2f). This area had been graded and it is possible that the geomorphic features had been destroyed. However, the grading exposed unfaulted lacustrine deposits across the trace of these tonal lineaments. Farther to the south, additional tonal lineaments were verified in the field (Figure 2f).

Fault G

Fault G mapped by Weick in the easternmost Madeline Plains is a north-trending zone of both west and east-facing scarps in bedrock (Figure 2f). The southern extent of Fault G offsets late Pleistocene lacustrine deposits (Weick, 1990) (Figure 2f).

The fault zone in bedrock is poorly defined and is delineated by subdued scarps and tonal lineaments (Figure 2f). The southern extent of Fault G mapped by Weick is delineated by a broadly arcuate scarp. The southernmost extent of this fault most closely represents a shoreline, based on aerial photographic interpretation and field inspection by this writer. The scarp crest is level, the scarp slope angle of 12° to 14° is more consistent with other shorelines observed in the Madeline Plains area, and two additional west-facing scarps (old shorelines?) are located just above this feature (locality 25, Figure 2f). Weick did not locate the southern part of his Fault G accurately as is shown in Figure 2f.

Fault west of Fault A

One of the more recent-looking faults in the Madeline Plains area is a broadly arcuate, east-facing scarp in basaltic bedrock mapped by all workers and located west of Weick's Fault A (Figure 2e). This fault is characterized by down to the east normal displacement. The east-facing scarp in bedrock is moderately well-defined. Geomorphic evidence suggestive of late Quaternary offset includes ponded alluvium and a possible closed depression near the summit of McDonald Peak. Drainages have incised through the bedrock scarp, thus indicating a lack of latest Pleistocene to Holocene displacement. Latest Pleistocene shorelines on the north side of the Madeline Plains also are not offset where crossed by the fault.

LATE QUATERNARY STRATIGRAPHY OF WEICK

There are three key alluvial units mapped or discussed by Weick (1990) in the Madeline Plains: "pre-Lahontan gravels", "Sehoo Formation", and "Fallon Formation". The "Sehoo" unit is assumed by Weick to be a late Pleistocene lacustrine unit, while the "Fallon" unit is assumed to be a mid-Holocene (~5,000 ybp) lacustrine high stand unit. These formation names were proposed by Morrison (1964) and Morrison and Frye (1965) for lacustrine deposits in the southern Carson Desert (Fallon area) and along the Truckee River drainage between Nixon and Wadsworth (Pyramid Lake area) in Nevada.

Although Weick did not differentiate between Seho and Fallon deposits on his map, he does make a distinction in his evaluation of the activity of the Likely fault zone. Weick assumed that a late Pleistocene (13 to 15 ka) lacustrine high stand occurred in the Madeline Plains at about the 1706 meter (5600 feet) elevation, and that a mid-Holocene high stand occurred about 5,000 years ago and formed a well-defined highstand shoreline (in basalt) at the 1645 meter (5400 foot) elevation. He then makes the assumption that deposits that occur below the 1645 meter elevation are mid-Holocene in age.

This seems to be an unreasonable interpretation. Weick provides no data on soil development for the lacustrine deposits, nor does he provide any data on thicknesses or contact relationships between the Seho and Fallon Formations in the Madeline Plains. The Madeline Plains lies at an elevation of about 1615 meters (5300 feet), so he is proposing that the Madeline Plains was filled with about 30 meters of water about 5000 years ago. Morrison and Frye (1965) concluded from data in the Fallon and Pyramid Lake areas that a mid-Holocene highstand may have extended to a depth of about 45 meters in the Lahontan Basin. Weick has assumed that a depth of 30 meters was attained in the Madeline Plains during this same time period. This is unrealistic because: 1) the drainage area surrounding the Madeline Plains is only a fraction of that draining into the Lahontan Basin and 2) the Madeline Plains was never connected with the Lahontan Basin. There may have been a minor, mid-Holocene pluvial period that affected the Madeline Plains, but to assume that the 1645 meter high stand represents this minor period is untenable.

It further seems unreasonable that the 1645 meter shoreline features are 5,000 years old because there are no well-defined shoreline features at the 1706 meter elevation in the Madeline Plains (except for a poorly defined bench at Dill Butte in the southern Madeline Plains). Further, there is an outlet at the southern end of Madeline Plains (Spanish Springs) at elevation 1673 meters (5491 feet) about 4 km south of the study area. Thus, it is unreasonable to conclude that the 1645 meter elevation represents the late Pleistocene lacustrine highstand that occurred throughout the Basin and Range at about 15 ka.

SEISMICITY

The study area is characterized by a paucity of seismic activity. A and B quality epicenters in the Canby-Madeline Plains study area have not been recorded (CIT, 1985) and only a few epicenter locations of lesser quality have been recorded in the vicinity of the trace of the Likely fault zone. The Likely fault may lack seismicity, but this in part may be due to the area being poorly instrumented.

CONCLUSIONS

LIKELY FAULT

The Likely fault zone has been described as an 85 to 95 km long, right-lateral strike-slip or right-oblique slip fault (Gay and Aune, 1958; CDM, 1959; Lydon and others, 1960; Macdonald, 1966; Weick, 1990). CDM (1959) reported that the Likely fault may be a significant strike-slip fault delineated by "sag ponds and disrupted topography" suggestive of recent displacement. Weick (1990) reported that traces of the southern Likely fault in the Madeline Plains are characterized by geomorphic evidence of Holocene right-lateral oblique displacement and offset lacustrine deposits of mid-Holocene age ("Fallon Formation").

Both Potter (1988) and Howard (1988) provided evidence contrary to this assessment of the Likely fault. Potter did not verify the existence of a throughgoing strike-slip or normal fault in the Canby area

(Figure 2a). Howard concluded that the Likely fault is a "zone of fortuitously aligned normal faults and photolineaments found to be largely caused by homoclinal-tilted strata." Howard, who based his evaluation on air photo interpretation and field inspection, stated that no compelling evidence of Holocene activity was observed along the fault's trend.

The Likely fault in general is moderately to poorly defined and lacks geomorphic evidence of latest Pleistocene to Holocene right-lateral or normal displacement, based on air photo interpretation and field inspection by this writer (Figures 2a-2f). The northern part of the Likely fault in the Canby area may not exist. Exposures of Miocene and Pliocene bedrock show unfaulted bedrock across the mapped traces of the Likely fault, verifying the work of Potter (1988) (localities 2 and 3, Figure 2a). Northeast-dipping beds and flow surfaces of the Miocene Cooley Gulch Formation of Potter form prominent strike-ridges south of the Pit River. A north-trending bedrock fault crosses the mapped trace of the Likely fault and is not offset (locality 7, Figure 2a).

Southeast of the Canby quadrangle the Likely fault is delineated by scarps, broad linear troughs, large closed depressions, and right-laterally offset large drainages in resistant bedrock that are indicative of late Quaternary right-lateral strike-slip or right-oblique displacement (e.g. localities 19 and 20, Figure 2d). However, individual traces lack well-defined geomorphic evidence of latest Pleistocene to Holocene offset. The fault lacks the systematic deflection of drainages one would expect for a significant, Holocene active strike-slip fault in generally resistant bedrock. Drainages are deflected both right and left-laterally, while other drainages cross the fault with no evidence of deflection (Figures 2b-2f).

The conclusions of Weick (1990) regarding the activity along traces of the Likely fault in the Madeline Plains area were not verified by this writer. Traces of the Likely fault are not delineated by geomorphic evidence of Holocene strike-slip or oblique-slip displacement and are poorly defined in resistant bedrock (Figures 2e and 2f). Tonal lineaments (linear vegetation contrasts in alluvium) mapped by Weick were verified along Fault D (Figure 2f). However, no associated geomorphic evidence of faulting was observed during field inspection by this writer, and latest Pleistocene shorelines are not obviously offset by this fault. It could be argued that the vegetation contrast in latest Pleistocene to Holocene lacustrine deposits is indicative of Holocene offset. This is weak evidence when viewed in the context of the lack of youthful geomorphic expression of the fault in resistant bedrock both northwest and southeast of this short vegetation contrast. More likely, this vegetation contrast delineating Fault D in the northern Madeline Plains reflects the presence of an old, inactive fault in bedrock that lies just below the surface in this area.

SELECTED NORTH-TRENDING FAULTS NEAR LIKELY FAULT ZONE

North-trending normal faults near the Likely fault zone generally are better defined than the northwest-trending strands of the Likely fault zone. However, these north-trending faults (such as Weick's Faults F and G) generally lack geomorphic evidence of latest Pleistocene to Holocene displacement.

The Nelson Corral fault mapped by Burnett (unpublished) is delineated by moderately to poorly defined tonal lineaments in latest Pleistocene to Holocene alluvium in the Madeline Plains (Figure 2c). A bedrock fault on trend with these lineaments north of Madeline Plains lacks geomorphic evidence of latest Pleistocene to Holocene normal displacement. Additional sub-parallel lineaments southwest of the Nelson Corral fault (Traces 1 and 2) are associated with bedrock faults north of Madeline Plains.

However, these bedrock faults lack geomorphic evidence of recent faulting and late Pleistocene high stand shorelines are clearly not offset along the northern projection of Traces 1 and 2 (Figure 2c).

RECOMMENDATIONS

Recommendations for zoning faults for special studies are based on the criteria of "sufficiently active" and "well-defined" (Hart, 1988).

LIKELY FAULT ZONE

Do not zone for special studies. The fault zone is not sufficiently active and most traces are not well-defined.

SELECTED NORTH-TRENDING FAULTS NEAR LIKELY FAULT ZONE

Do not zone north-trending faults near the Likely fault zone (Nelson Corral and related; Faults F and G; fault west of Fault A). These faults are not sufficiently active and mostly not well-defined.

*Reviewed and
approved for file
Paul W. Hart
CEG-935
3/22/91*

William A. Bryant

William A. Bryant
Associated Geologist
R.G. #3717
August 13, 1990
(Revised March 20, 1991)

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